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Acute Toxicity of Kelthane, Dursban, Disulfoton, Pydrin, and Permethrin to Fathead Minnows 'Pimephales promelas' and Rainbow Trout 'Salmo gairdneri'

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THE ACUTE TOXICITY OF KELTHANE, DURSBAN, DISULFOTON, PYDRIN, AND PERMETHRIN TO FATHEAD MINNOWS *PIMEPHALES PROMELAS* AND RAINBOW TROUT *SALMO GAIRDNERI*

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ABSTRACT

Flow-through acute lethal toxicity tests were conducted with kelthane, dursban disulfoton, pydrin and permethrin using rainbow trout Salmo gairdneri *and fathead minnows* Pimephales promelas *in Lake Superior water. Pydrin was the most toxic pesticide tested to both species of fish and was followed in order of decreasing toxicity by permethrin, dursban, kelthane and disulfoton. Rainbow trout were more sensitive than fathead minnows to all five pesticides. The 96-h LC_{50} values (μg litre^{-1}) for rainbow trout and fathead minnows, respectively, were: pydrin, 2·1 and 5·4; permethrin, 7·0 and 15·6; dursban, 8·0 and 203·0; kelthane, 210·0 and 510·0 and disulfoton, 3020·0 and 4000·0.*

INTRODUCTION

Recently, many new broad-spectrum pesticides have been developed that have the potential for widespread use in the environment. In large-scale applications of these pesticides by methods like crop dusting, orchard and forest spraying, or mosquito control, some inevitably enter aquatic ecosystems. Knowledge of the effects of these broad-spectrum pesticides on aquatic organisms is necessary before their large-scale use is allowed.

The present tests were conducted to determine the acute toxicological effects of technical grades of kelthane, dursban, disulfoton, pydrin and permethrin on juvenile rainbow trout *Salmo gairdneri* and fathead minnows *Pimephales promelas*. Fatheads and trout were tested to elucidate sensitivity differences between these commonly tested warm and cold water fish species. The five compounds tested are all potential broad-spectrum pesticides which represent three basic pesticide groups. Kelthane is a chlorinated hydrocarbon, dursban and disulfoton are organophosphorus compounds and pydrin and permethrin are synthetic pyrethroids.

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Limited data on acute lethal toxicity to fish are available in the literature for these five pesticides. Those for rainbow trout are available for kelthane (Johnson & Mayer, 1973), dursban (Macek *et al.*, 1969; Johnson & Finley, 1981), disulfoton (Johnson & Finley, 1981) and for pydrin and permethrin (Mulla *et al.*, 1978; Coats & O'Donnell-Jeffery, 1979; unpublished data are available from the Columbia National Fishery Research Laboratory, Columbia, Missouri). For fathead minnow, they are available for dursban (Jarvinen & Tanner, 1982), disulfoton (Johnson & Finley, 1981) and for pydrin and permethrin (unpublished data, Columbia National Fishery Research Laboratory). With the exception of studies by Jarvinen & Tanner (1982), which used flow-through conditions and no solvents, and Mulla *et al.* (1978), which used a water emulsifiable concentrate formulation under static conditions, all preceding tests were conducted under static conditions using a solvent to solubilise the pesticide compounds. Very little is known about solvent effects and interactions on biological organisms and test compounds. For this reason, the present tests were conducted under flow-through conditions without the use of solvent carriers.

MATERIALS AND METHODS

Exposure system

All tests were conducted using proportional diluters (Mount & Brungs, 1967) with dilution factors of 0·6. Each diluter cycle delivered 2 litres of water or water plus pesticide to flow-splitting chambers (Benoit & Puglisi, 1973) which delivered 1 litre of water to randomised duplicates of five pesticide concentrations plus a control. The glass exposure tanks measured 60 × 30 × 30 cm deep with a 10 cm water depth and a tank volume of 18 litres. Flow rates were varied for the individual studies, depending on each pesticide's solubility in the saturator and/or the stability of the compound in the test water. Flow rates and 90% replacement time of the test water, determined using the method of Sprague (1969), were: kelthane, 83 ml min^{-1} and 8 h; dursban, 74 ml min^{-1} and 9 h; disulfoton, 81 ml min^{-1} and 8 h; pydrin, 137 ml min^{-1} and 5 h and permethrin, 60 ml min^{-1} and 12 h. A constant 16-h photoperiod was used. Fluorescent lamps provided a light intensity of 28 lumens at the water surface.

Water characteristics

Water for all tests was obtained from Lake Superior and heated to 15·6 ± 1·8 °C for rainbow trout and 25·1 ± 1·3 °C for fathead minnow. All water quality characteristics were measured using methods described by the American Public Health Association *et al.* (1975). Hardness, alkalinity and pH determinations were made on three duplicate tanks including the control and high concentration. Means and ranges for hardness and alkalinity were 45·3 (43·7–46·5) and 41·8 (39·6–43·2) mg $litre^{-1}$ as $CaCO_3$, respectively, for all tests. The pH ranged from 7·0 to 7·4.

The mean dissolved oxygen was 9·3 mg litre^{-1} (range = 7·5–11·3) for all rainbow trout tests and 7·3 mg litre^{-1} (range = 6·7–7·7) for the fathead minnow tests.

Toxicant solutions

Commercial, alternative and chemical names of the five pesticides tested, along with purity and the chemical companies which provided these compounds, are listed in Table 1. All pesticides were solubilised using a saturator system similar to the one described by Phipps *et al.* (1982). In all cases, the saturator consisted of three 19-litre pop cans that were connected in series. Two of the three cans were heated in a water bath to ~35 °C and the contents stirred with a magnetic stir bar. No solvents were used with any of the tested compounds. Kelthane was coated onto stainless steel screens which were placed inside the saturator cans, while the remaining four pesticides were coated directly on the inside or on the bottom of the cans. Depending on the solubility and toxicity of each pesticide, a predetermined amount of saturated liquid was pumped to the diluter during each cycle using a metering pump controlled by a time delay relay.

Pesticide concentrations were analysed daily on samples taken at mid-depth of each tank from one complete set of duplicates. All analyses were conducted on a Hewlett Packard 5710A Gas Chromatograph (GC) with an autosampler and a Ni-63 electron capture cell. Water samples were vigorously mixed with hexane before GC analysis and, if necessary, were further diluted or concentrated. The column for kelthane was a 1·8 m × 2 mm (ID) glass coil filled with 4 % SE30 and 6 % OV-210 on 80/100 mesh Gas Chrom Q. For dursban and disulfoton, the column was a 1·8 m × 2 mm (ID) glass coil filled with 1·5 % OV-17 and 1·95 % QF-1 on 80/100 mesh Gas Chrom Q. The column for pydrin and permethrin was a 1·0 m × 2 mm (ID) glass coil filled with 3 % OV-7 on 80/100 mesh Chromosorb W-HP. Carrier gas used for all compounds was argon containing 5 % methane. Flow rates of the carrier gas were 50·0, 26·7, 26·7, 35·0 and 35·0 ml min^{-1} for kelthane, dursban, disulfoton, pydrin and permethrin, respectively. Analyses were made at column temperatures of 195 °C for kelthane, 190 °C for dursban and 195 °C for disulfoton. With pydrin and permethrin, the initial temperature was 220 °C, the injection temperature was 250 °C and the detector temperature was 300 °C. The attenuation used for all pesticides was 8 ×. Detection limits for kelthane, dursban, disulfoton, pydrin and permethrin were approximately 1·0, 0·3, 4·0, 0·02 and 0·02 μg litre^{-1}, respectively. Measured water concentrations and percentage recoveries from spiked samples are presented in Table 2.

Biological procedures

Fathead minnow tests were conducted using 31- or 32-day-old fish which were obtained as newly hatched larvae from the stock culture unit of the Environmental Research Laboratory—Duluth, Minnesota. Larvae were kept in a rearing system similar to the exposure system and were fed live San Francisco Bay brine shrimp

TABLE 1

COMMERCIAL, ALTERNATIVE AND CHEMICAL NAMES OF THE PESTICIDES TESTED, PURITY, AND THE CHEMICAL COMPANIES WHICH PROVIDED THESE COMPOUNDS FOR TESTING

Commercial	*Alternative names*	*Chemical names*	*Percent active ingredient of the technical grade pesticides*	*Chemical company*
Kelthane	DicoFol, Acarin, ENT-23648, FW-293, Mitigan	4,4'-Dichloro-α-trichloro-methylbenzhydrol	87·3	Rohm & Haas, Co., Agriculture Div., Independence Mall West, Philadelphia, PA 19105
Dursban	Lorsban, chlorpyrifos, Dowco 179, ENT27311	*O,O*-Diethyl *O*-3,5,6-trichloro-2-pyridyl phosphorothionate	99·9	Dow Chemical Co., Agricultural Products Dept., Midland, MI 48640
Disulfoton	Di-Syston, Dithiosystox, Thiodemeton, S 276, Phosphorodithionic acid, Bayer 19 639, Dithiodemeton, Solvirex, Frumin AL	*O,O*-Diethyl S-2-(ethylthio)ethyl phosphorodithioate	98·1	Mobay Chemical Corp., Agricultural Chem. Div., 8400 Hawthron Rd., Kansas City, MO 64120
Pydrin	Fenvalerate, Sumicidin, Belmark, WL 43775, S-5602, Sanmarton, Sumifly, Sumipower, SD-43775	Cyano-3-phenoxybenzyl 2-(4-chlorophenyl)-3-methylbutyrate	97·0	Shell Development Co., Biological Science Research Center, Modesto, CA 95352
Permethrin	Pounce, Ambush, NRDC 143, BW-21-Z, Ectiban, FMC-33297 PP557-(ICI), SBP-1513	3-Phenoxybenzyl(±)*cis,trans*-3-(2,2-dichlorovinyl)-2,2-dimethylcyclopropane carboxylate	91·9	ICI—United States, Agricultural Chemicals Div., Wilmington, DE 19897

TABLE 2

MEASURED WATER CONCENTRATIONS, EXPRESSED AS MICROGRAMS OF ACTIVE INGREDIENT PER LITRE, AND PERCENTAGE SPIKE RECOVERIES FOR FIVE PESTICIDES TESTED WITH FATHEAD MINNOWS AND RAINBOW TROUT

Compound	*Species*	*Tank No. 1 (control)*	*Tank No. 2*	*Tank No. 3*	*Tank No. 4*	*Tank No. 5*	*Tank No. 6*	*Percentage spike recoveries[c]*
Kelthane	Fathead	1·0 ± 2·0[a]	—[b]	—[b]	218·0 ± 57·0	400·0 ± 96·0	543·0 ± 128·0	84·5 ± 17·7[a]
Kelthane	Rainbow	1·0 ± 0·0	—[b]	74·0 ± 7·0	145·0 ± 25·0	238·0 ± 10·0	420·0 ± 14·0	85·8 ± 5·3
Dursban	Fathead	1·0 ± 1·0	47·0 ± 5·0	70·0 ± 3·0	122·0 ± 16·0	220·0 ± 35·0	383·0 ± 21·0	99·8 ± 4·1
Dursban	Rainbow	0·0 ± 0·0	1·5 ± 0·1	2·7 ± 0·3	5·0 ± 0·4	7·7 ± 0·6	17·0 ± 2·0	92·7 ± 6·7
Disulfoton	Fathead	0·0 ± 0·0	413·0 ± 72·0	1303·0 ± 290·0	2000·0 ± 337·0	3975·0 ± 585·0	5700·0 ± 1414·0	100·7 ± 22·4
Disulfoton	Rainbow	0·0 ± 0·0	540·0 ± 29·0	—[b]	1600·0 ± 0·0	2800·0 ± 163·0	6675·0 ± 714·0	104·0 ± 9·5
Pydrin	Fathead	1·0 ± 1·0	1·6 ± 1·0	2·3 ± 0·1	2·5 ± 0·7	3·6 ± 0·4	10·1 ± 0·9	105·0 ± 3·0
Pydrin	Rainbow	0·0 ± 0·0	0·7 ± 0·3	1·3 ± 0·3	3·5 ± 1·1	4·6 ± 1·2	13·3 ± 4·7	105·7 ± 2·5
Permethrin	Fathead	0·0 ± 0·0	7·2 ± 1·5	17·9 ± 2·8	36·7 ± 7·4	42·4 ± 3·1	110·7 ± 5·4	97·3 ± 2·5
Permethrin	Rainbow	0·0 ± 0·0	7·0 ± 2·6	14·7 ± 0·4	17·8 ± 3·4	29·8 ± 17·1	76·7 ± 32·0	90·3 ± 10·4

[a] Mean and standard deviation.
[b] These tanks were deleted in order to get the upper tanks to higher concentrations.
[c] Mean of four spiked samples.

TABLE 3

THE AVERAGE WEIGHT OF EXPOSED FATHEAD MINNOWS AND RAINBOW TROUT, THE 24-, 48-, 72- AND 96-h LC_{50} VALUES[a] EXPRESSED AS MICROGRAMS OF ACTIVE INGREDIENT PER LITRE FOR THE FIVE PESTICIDES, AND THE SENSITIVITY FACTORS BETWEEN SPECIES

Compound	*Species*	*Average weight of exposed fish (g)*	*24-h LC_{50}*	*48-h LC_{50}*	*72-h LC_{50}*	*96-h LC_{50}*	*Sensitivity factor: LC_{50} Fathead/LC_{50} Rainbow*
Kelthane	Fathead	0·2	—[b]	—[b]	—[b]	510·0 (488·0–533·0)	2·4
Kelthane	Rainbow	1·9	335·0 (307·0–365·0)	309·0 (268·0–357·0)	262·0 (232·0–296·0)	210·0 (181·0–244·0)	
Dursban	Fathead	0·1	320·0 (285·0–360·0)	248·0 (225·0–273·0)	220·0 (204·0–236·0)	203·0 (191·0–217·0)	25·4
Dursban	Rainbow	1·0	—[b]	11·4 (10·8–12·2)	8·0 (6·8–9·4)	8·0 (6·8–9·4)	
Disulfoton	Fathead	0·2	4410·0 (4220·0–4610·0)	4050·0 (3850·0–4250·0)	4030·0 (3830·0–4230·0)	4000·0 (3810·0–4210·0)	1·3
Disulfoton	Rainbow	4·3	4320·0 (4320·0–4320·0)	3880·0 (3470·0–4350·0)	3020·0 (2580·0–3550·0)	3020·0 (2580·0–3550·0)	
Pydrin	Fathead	0·1	6·1 (6·0–6·3)	5·9 (5·6–6·2)	5·9 (5·6–6·2)	5·4 (5·1–5·6)	2·6
Pydrin	Rainbow	4·0	4·7 (3·6–6·1)	2·8 (2·2–3·5)	2·2 (1·8–2·7)	2·1 (1·7–2·5)	
Permethrin	Fathead	0·1	40·3 (30·2–53·7)	32·1 (23·9–43·2)	20·4 (9·9–42·3)	15·6 (8·5–28·8)	2·2
Permethrin	Rainbow	0·5	25·8 (20·4–32·6)	17·4 (13·9–21·9)	11·4 (7·2–18·2)	7·0[c] (7·0–7·0)	

[a] These LC_{50} values represent the combined duplicate tank mortality with the 95% confidence intervals in parentheses.
[b] No LC_{50} values could be determined because of insufficient mortality in the highest exposure concentrations.
[c] Sixty percent mortality occurred in the low concentration in one duplicate tank and the LC_{50} was calculated from the remaining duplicate exposure.

until used for testing. Juvenile rainbow trout obtained from Fattig Hatcheries, Brady, Nebraska, were held in a 530-litre fibreglass holding tank at 12 °C and fed a commercial formulation of dry food. Groups of 50 fathead minnow or 10 rainbow trout were counted into 12 containers and were then randomly assigned to the exposure tanks at the start of each test. Fish were not fed 24 h before or during a test. Average weights of exposed fish were obtained by weighing subsamples of 50 fathead minnow and 20 rainbow trout and are given in Table 3. Death was the primary endpoint, although effects on equilibrium, behaviour, coloration and deformities were also noted. Qualitative schooling behaviour (the location, orientation and grouping pattern of fish in a tank) observations were made using visual comparisons between exposed fish and controls. Dead fish were counted and removed and other observations made four times during the first day and twice daily thereafter. Determinations of LC_{50} values were made using a computerised Trimmed Spearman Karber method (Hamilton *et al.*, 1977). Mortality data from the duplicate exposure tanks were combined before LC_{50} determinations were conducted. Other procedures or methods not specified followed the basic flow-through acute toxicity test method described by the US Environmental Protection Agency (1975).

RESULTS

The 24-, 48-, 72- and 96-h LC_{50} values for both species of fish for all tested pesticides are listed in Table 3. Comparisons of the 96-h LC_{50} values indicate that pydrin was the most toxic of the pesticides tested to both fathead minnow and rainbow trout. Pydrin was followed in order of decreasing toxicity by permethrin, dursban, kelthane and disulfoton.

Rainbow trout were more sensitive to all tested pesticides than were fathead minnows. Sensitivity factors, derived by dividing the 96-h LC_{50} value for fathead minnow by the 96-h LC_{50} for rainbow trout, ranged from 1·3 for disulfoton to 25·4 for dursban (Table 3).

Observations made on factors other than mortality are summarised by compound as follows:

Kelthane

Normal schooling behaviour was absent in fathead minnows exposed to 218 μg litre^{-1} and above after 24 h. The fish in these concentrations were lethargic after 78 h. Rainbow trout exposed to 238 μg litre^{-1} appeared lethargic and exhibited flared opercula, gaping mouths and rapid gill movements after 48 h. After 72 h, 8 of 14 remaining trout exposed to 238 μg litre^{-1} developed a darker body coloration than either control fish or those exposed to lower concentrations. All remaining fish had developed a darker body coloration after exposure to 238 μg litre^{-1} for 96 h and 50% of these remaining trout had lost equilibrium.

Dursban

Schooling behaviour of fathead minnows exposed to 47 μg litre^{-1} and above was disrupted at 24 h and thereafter throughout the test; after 48 h, in all dursban exposures they appeared to have stiff vertebral columns and several fish at all dursban concentrations had developed definite spinal deformities. Spinal deformities in rainbow trout became obvious after 30 h of exposure to 5·0 μg litre^{-1} and above. Trout developed darkened areas just anterior or posterior to the dorsal fin and the fish became deformed at these darkened areas. In some cases, the darkened areas were just small spots while in other fish the entire caudal peduncle darkened. Darkened areas tended to disappear after deformities occurred. Forty-one per cent of the 17 surviving trout exposed to 5·0 μg litre^{-1} developed deformed vertebral columns after 72 h, but only 24% of these fish lost equilibrium.

Disulfoton

Normal schooling behaviour of fathead minnows was disrupted and several fish developed haemorrhaged areas just anterior or posterior to the dorsal fin in concentrations of 413 μg litre^{-1} and above after 24 h. A few fish with haemorrhaged areas also exhibited deformed vertebral columns at this haemorrhaged location. Vertebral columns of fish with haemorrhaged areas anterior to the dorsal fin appeared severed. After 78 h, haemorrhaged areas were apparent in approximately 40, 60 and 90% of the fathead minnows exposed at levels of 413, 1303 and 2000 μg litre^{-1}, respectively. Most fish with haemorrhaged areas also exhibited some degree of spinal deformity. Rainbow trout exposed to 2800 μg litre^{-1} were lethargic and had muscle spasms after 30 hours' exposure. After 72 h, trout exposed to 1600 μg litre^{-1} were lethargic and several developed a darker body coloration than fish exposed to lower concentrations.

Pydrin

Fathead minnows exposed to 3·6 μg litre^{-1} were hyperactive and darted about in short bursts after 48 h. Schooling behaviour was absent in fish exposed to 2·5 μg litre^{-1} and above for that time period. Rainbow trout exposed to 1·3 μg litre^{-1} and above for 48 h exhibited rapid gill movements and most were swimming at the water surface.

Permethrin

Schooling behaviour of fathead minnows was affected at 7·2 μg litre^{-1} and above after 3 h. In all toxicant exposures they exhibited erratic swimming and flared gills by 24 h. Several fish exposed to 17·9 μg litre^{-1} and above were floating ventral side up at the water surface. This was apparently due to the peritoneal cavities being distended with gas. After 72 h, remaining fish at all permethrin exposures appeared more emaciated than controls, were very sluggish, and most had lost equilibrium. Rainbow trout exposed to permethrin died very rapidly after equilibrium was lost.

Trout exposed to 7·0 μg litre^{-1} and above for 48 h frequently shook their heads, coughed (gill clearing attempts) and darted about.

These previously mentioned adverse sublethal effects were, in most cases, observed at levels below the 96-h LC_{50} values. Sublethal effects were observed with fathead minnow at exposure levels that were 0·4, 0·2, 0·1, 0·5 and 0·5 of the 96-h LC_{50} values determined for kelthane, dursban, disulfoton, pydrin and permethrin, respectively. Rainbow trout exhibited sublethal effects at exposure levels that were 1·1, 0·6, 0·5, 0·6 and 1·0 of the 96-h LC_{50} values determined for kelthane, dursban, disulfoton, pydrin and permethrin, respectively.

DISCUSSION

Even though water solubilities of these five technical grade pesticides are extremely low, no solvents were used to solubilise the compounds in this study. However, most previous tests dealing with technical grade formulations of these pesticides have been conducted under static conditions with the use of solvent carriers. Comparisons of LC_{50} values from the present tests with those previously available should be useful for elucidating whether any large differences exist between LC_{50} derived using various test methods.

Kelthane

Kelthane 96-h LC_{50} values were 210 and 510 μg litre^{-1} for rainbow trout and fathead minnows, respectively, in the present study. Although no rainbow or fathead 96-h acute data are available in the literature, Johnson & Mayer (1973) determined a 24-h LC_{50} of 110 μg litre^{-1} for rainbow trout exposed to kelthane in static tests using nominal concentrations and a solvent carrier. Johnson & Finley (1981) determined, for five species of fish, 96-h kelthane LC_{50} values which ranged from 53 μg litre^{-1} for cutthroat trout *Salmo clarki* to 520 μg litre^{-1} for bluegills *Lepomis macrochirus*.

Dursban

The 96-h LC_{50}s for dursban in the present study were 8·0 μg litre^{-1} for rainbow trout and 203·0 μg litre^{-1} for fathead minnow. This rainbow trout LC_{50} value compares very closely with the 96-h value of 7·1 μg litre^{-1} previously reported for rainbows exposed to dursban at 12·7 °C by Macek *et al.* (1969) using static tests with an acetone carrier. The 96-h LC_{50} of 140 μg litre^{-1} (Jarvinen & Tanner, 1982) determined for fathead minnow using flow-through conditions and no solvents compares quite closely to the dursban fathead minnow LC_{50} from the present study. Dursban data from static tests are also available for other freshwater fish species. El-Refai *et al.* (1976) conducted tests on two sizes of carp *Cyprinus carpio* and tilapia *Tilapia nilotica* and found 48-h LC_{50}s ranging from 59 to 280 μg litre^{-1}. Davey *et al.* (1976) determined 72-h dursban LC_{50} values of 40 and 260 μg litre^{-1} for green

sunfish *Lepomis cyanellus* and mosquitofish *Gambusia affinis*, respectively. Mosquitofish, green sunfish and golden shiners *Notemigonus crysoleucas* collected from two locations and tested with technical grade dursban yielded 36-h LC_{50} values ranging from 22·5 to 595 μg litre^{-1} (Ferguson *et al.*, 1966). Dursban 96-h LC_{50} data generated by Johnson & Finley (1981) on five species of fish ranged from 2·4 μg litre^{-1} for bluegills to 280 μg litre^{-1} for channel catfish *Ictalurus punctatus*.

Disulfoton

Disulfoton 96-h LC_{50} values were 3020 μg litre^{-1} for rainbow trout and 4000 μg litre^{-1} for fathead minnows in the present study. Johnson & Finley (1981) also tested rainbow trout and fathead minnows along with three other fish species under static conditions using a solvent. They determined 96-h LC_{50} values of 1850 and 4300 μg litre^{-1} for rainbow trout and fathead minnows, respectively, and found largemouth bass *Micropterus salmoides* to be the most sensitive species to disulfoton (96-h LC_{50} of 60 μg litre^{-1}). The fathead minnow LC_{50} value of the previously mentioned authors and the one from the present test are very close. In earlier static testing on technical grade disulfoton with four species of fish, Pickering *et al.* (1962) derived 96-h LC_{50} values ranging from 63 μg litre^{-1} for bluegills to 6500 μg litre^{-1} for goldfish *Carassius auratus*.

Pydrin

Pydrin 96-h LC_{50} values from the present tests were 2·1 and 5·4 μg litre^{-1} for rainbow trout and fathead minnow, respectively. Slightly lower values for technical grade pydrin were determined for rainbow trout and fathead minnows (unpublished data, Columbia National Fishery Research Laboratory) in a series of tests on five species of fish. They found 96-h LC_{50} values ranging from 0·32 to 1·7 μg litre^{-1} for rainbow trout and from 2·15 to 2·35 μg litre^{-1} for fathead minnows, while LC_{50} values for the three other species ranged from 0·75 to 2·4 μg litre^{-1}. Coats & O'Donnell-Jeffery (1979) also tested rainbow trout and determined a 24-h LC_{50} of 76 μg litre^{-1} for technical grade pydrin. Water emulsifiable concentrate formulations of pydrin were tested by Mulla *et al.* (1978) with four species of fish. Their rainbow trout 48-h LC_{50} (3·0 μg litre^{-1}) was very close to the 48-h LC_{50} (2·8 μg litre^{-1}) from the present test.

Permethrin

Static acute tests conducted on technical grade permethrin with a solvent carrier (unpublished data, Columbia National Fishery Research Laboratory) yielded a 96-h LC_{50} of 5·7 μg litre^{-1} for adult fathead minnows and a range of values from 2·9 to 8·2 μg litre^{-1} for rainbow trout depending on test conditions and fish size. Their LC_{50} values were only slightly lower than those of 15·6 and 7·0 μg litre^{-1} obtained for fathead minnows and rainbow trout, respectively, in the present study. In other work with rainbow trout, Coats & O'Donnell-Jeffery (1979) determined a 24-h LC_{50} of 135 μg litre^{-1} for technical grade permethrin. Jolly *et al.* (1978) tested several fish species with permethrin and found channel catfish to be the most sensitive species

with a 96-h LC_{50} of 1·1 μg litre^{-1}. Mulla *et al.* (1978) exposed rainbow trout and three other fish species to water emulsifiable concentrate formulations of permethrin and obtained results similar to the 96-h LC_{50} from the present test. They determined a 48-h LC_{50} of 6·0 μg litre^{-1} for rainbow trout.

Rainbow trout were more sensitive to all five pesticides tested than fathead minnows, and species sensitivity differences were quite small for kelthane, disulfoton, permethrin and pydrin during the present study. Previous studies with permethrin and pydrin (unpublished data, Columbia National Fishery Laboratory) and disulfoton (Johnson & Finley, 1981) conducted with rainbow trout and fathead minnows using static tests and solvents also substantiates that rainbows are more sensitive than fatheads and that species differences are small. The species sensitivity difference between rainbows and fatheads for dursban was 25·4 times in the present study. Species sensitivity differences as high as 39·4 times were noted between rainbow trout and channel catfish exposed to dursban (Johnson & Finley, 1981).

The present tests showed that the synthetic pyrethroid pesticides (pydrin and permethrin) were the most toxic of the three representative pesticide groups tested. Of the remaining two pesticide groups, the chlorinated hydrocarbon pesticide (kelthane) was less toxic than one organophosphate pesticide (dursban), but was more toxic than the other organophosphorus compound (disulfoton).

Organochlorine pesticides like kelthane are generally considered neurotoxicants in vertebrates (Johnson & Mayer, 1973). Disruptions of normal nerve functions may have produced the lethargic conditions observed in fathead minnows and rainbow trout exposed to kelthane. Concentrations of kelthane above 238 μg litre^{-1} also appeared to interfere with respiration in rainbow trout. Organophosphate pesticides like dursban and disulfoton inhibit cholinesterase, an enzyme involved in the control of the transmission of nerve impulses (Weiss, 1961, 1964; Thirugnanam & Forgash, 1977). Nerve transmission blockages could account for the spinal problems and the darkened or haemorrhaged areas that occurred in some fish exposed to dursban and disulfoton in the present study. Pyrethroid compounds are also known to be nerve poisons, but their mode of action at the molecular level remains obscure (Casida, 1980). Behavioural changes such as rapid gill movements and swimming at the water surface exhibited by some fish exposed to pydrin and permethrin indicate a respiratory effect. Effects on respiration caused by exposure to these compounds are likely since the lipophilicity of pyrethroids indicates they will be absorbed strongly by the gills of fish even from very low water concentrations (Elliott *et al.*, 1978). The emaciated condition of fathead minnows exposed to permethrin indicated that metabolism and/or activity was affected in these fish.

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